



Aircraft Propulsion:

Where We Are, Where We Might Go

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Green Aero-Propulsion: Outline of Talk

- Where we are
 - Aeropropulsion fundamentals & benchmarks
- Reducing Carbon footprint
 - Propulsion system technology
 - New fuels
- Trading one part of the environment for another?
 - It's tough being green!
- What does the future hold?

Context of Discussion

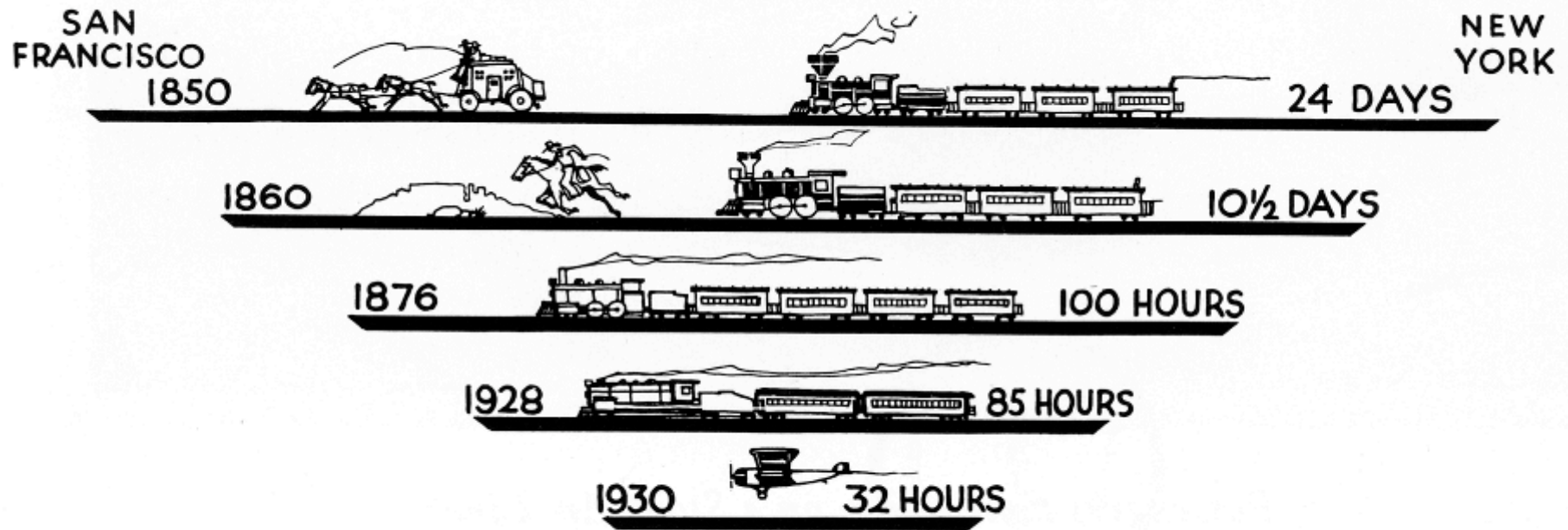
Aerospace is the largest manufacturing export of US



- Emphasis on what's important to the nation
- Answering society's need for transportation and defense

What Are We Trying to Accomplish?

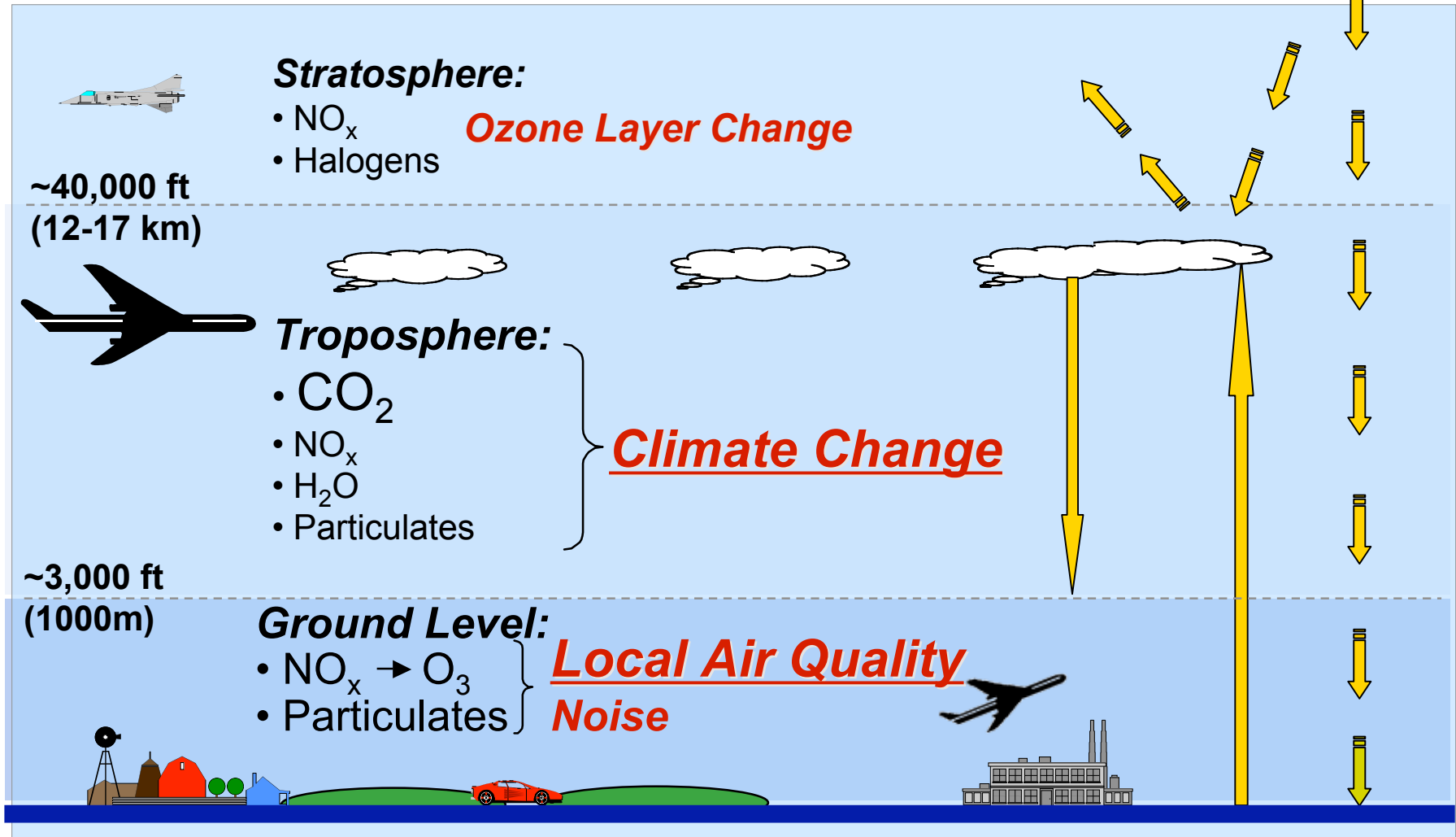
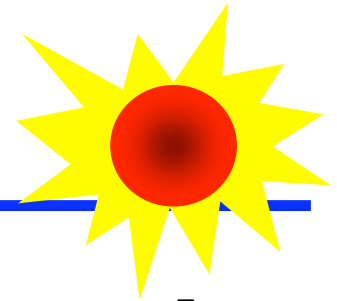
Measuring progress – United Aircraft Co., 1930



Diminishing Distance Across the Continent

- What we do now but at lower environmental cost?
- Enable new capabilities, new economics?

Impact of Aviation on The Environment



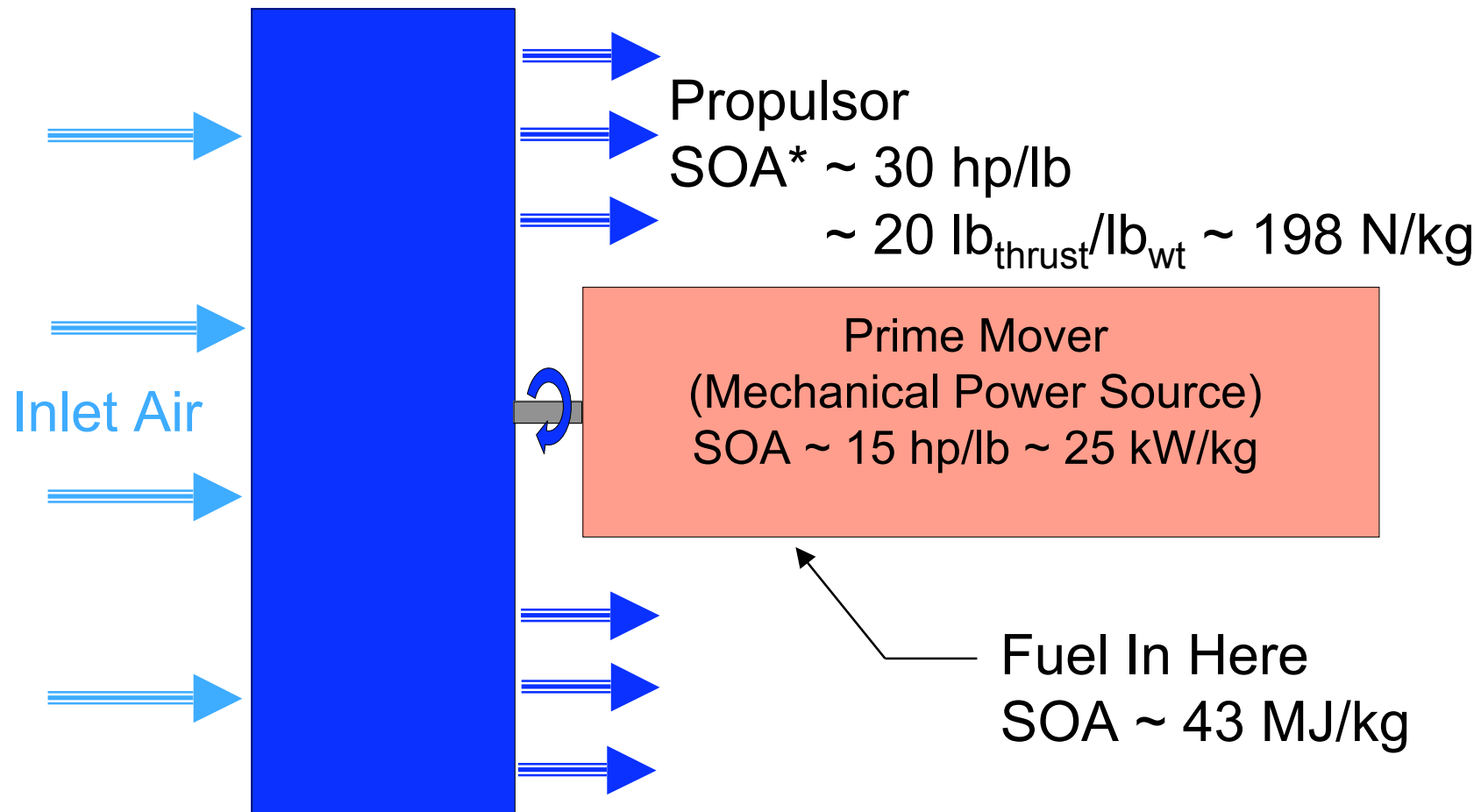
Establishing Perspective

*“The problem of the aviation engine is purely the combination of power and lightness and reliability”** *The Aero, Jan 1911

- What are the basics?
 - Current SOA
 - Physical limitations
- What’s new? New concept or old ideas with
 - New enabling technologies?
 - New needs?
- Innovation vs. Novelty
 - Useful? Or just interesting?

Propelling an Air Vehicle

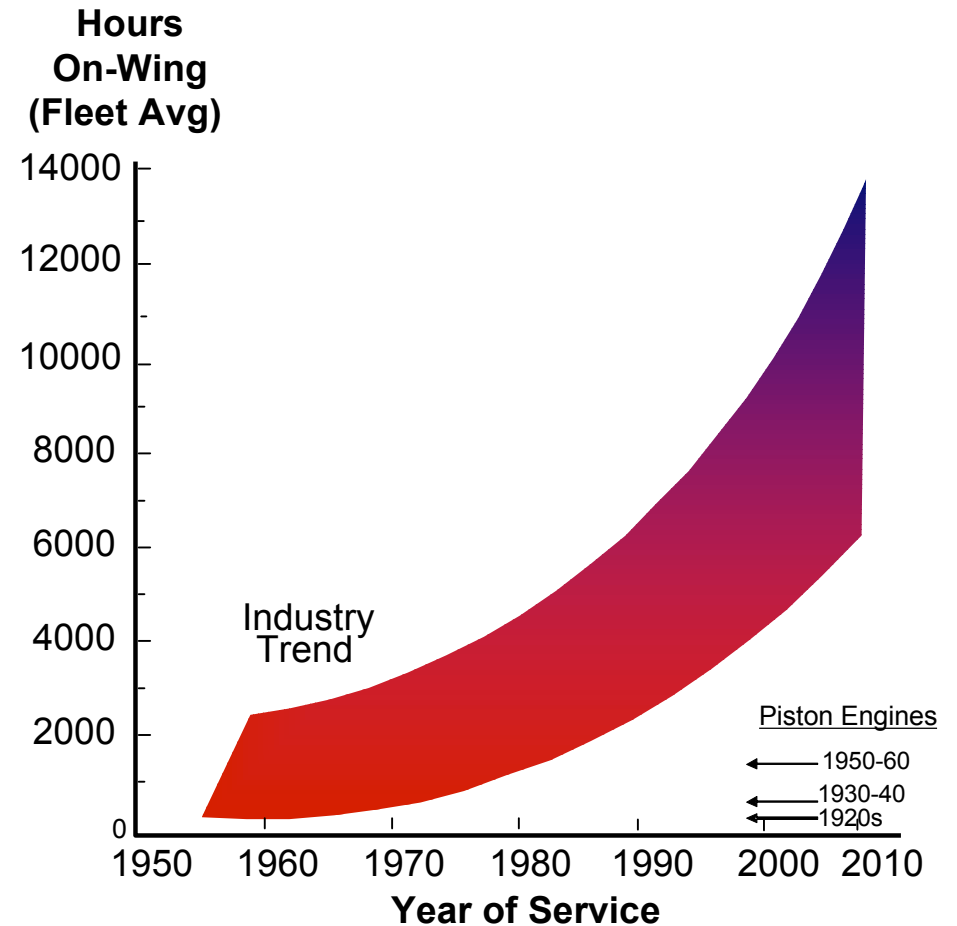
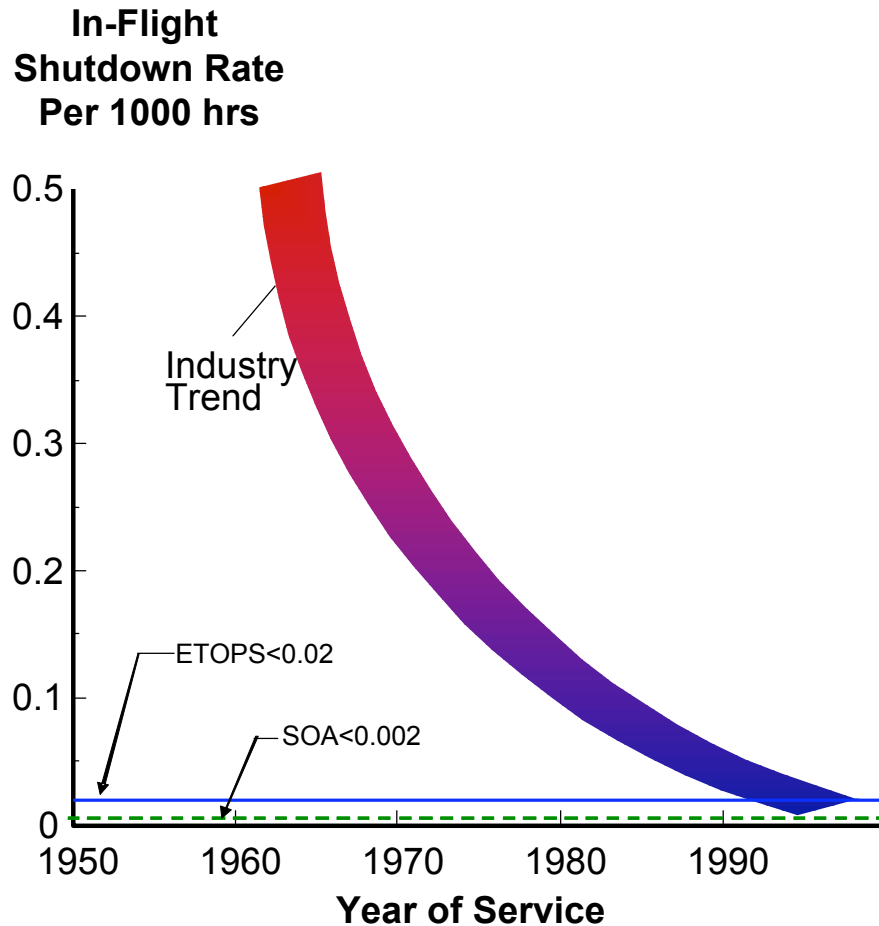
“...the combination of power and lightness...”



* Commercial Transport Engine at Sea Level

Propelling An Air Vehicle

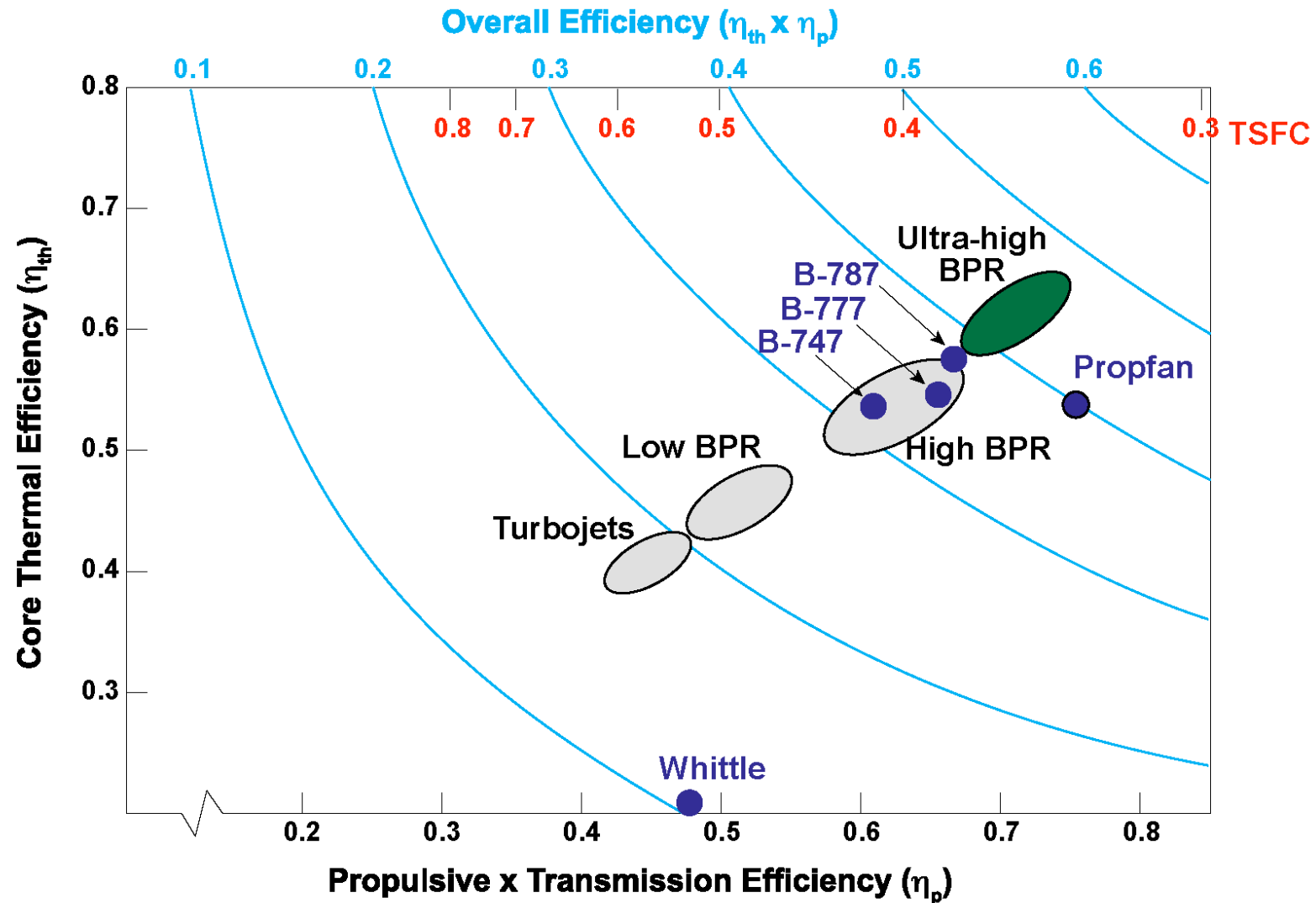
“...and reliability”



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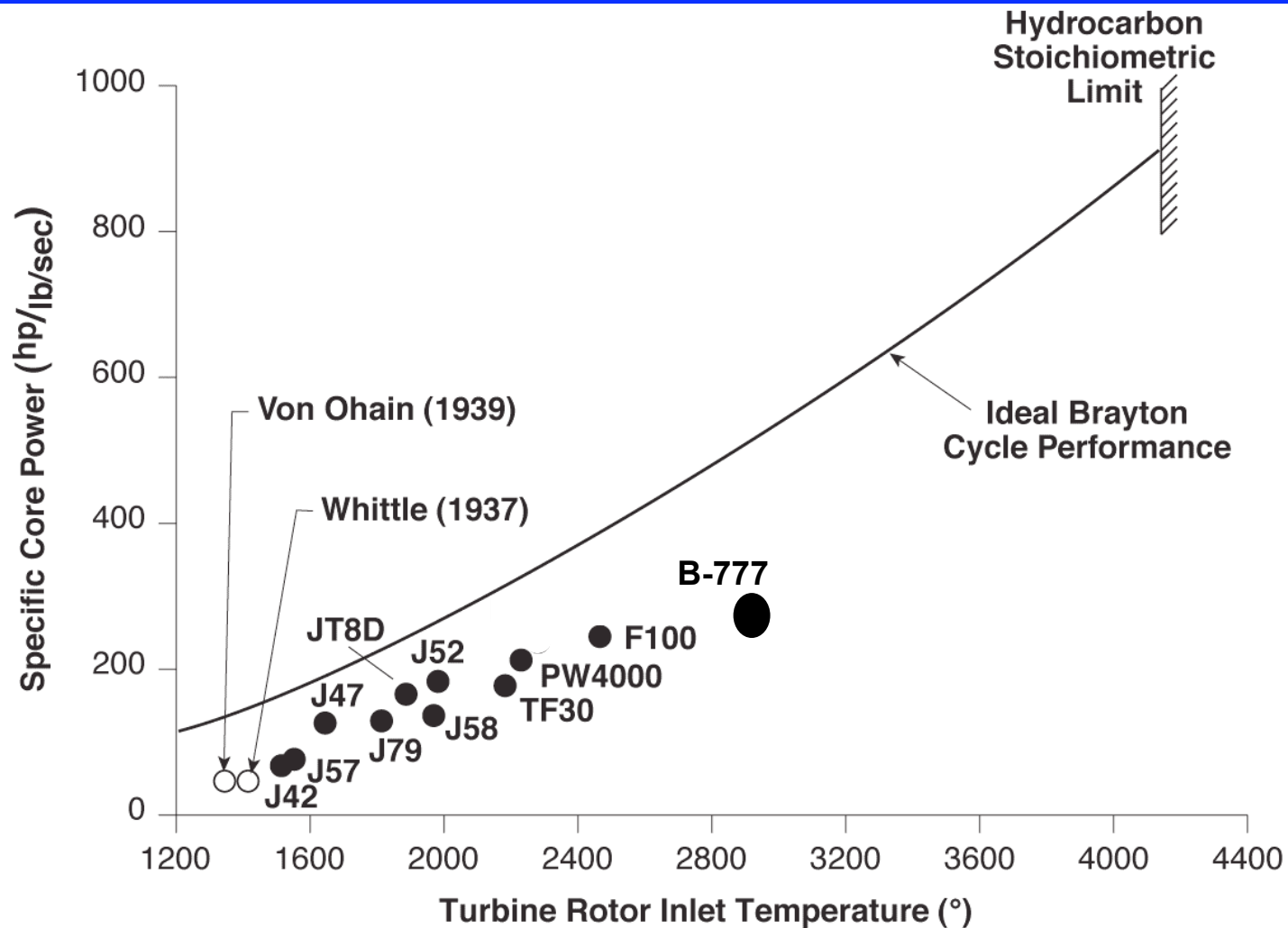
Evolution of Gas Turbine Efficiency



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History of Gas Turbine Specific Power



The Current State of the Art Summary

Subsonic transport engines

- Efficiency
 - Thermal efficiency = 50~60%
 - Propulsive x Transmission efficiency = 65~70%
- Weight
 - Engine Power/Wt = 6 hp/lb
 - Core Power/Wt = 15 hp/lb
 - Propulsor Drive System (LPT+shaft) = 32 hp/lb
 - 1000 lbs of propulsion system wt ~ 1% TSFC (B-737)
- Reliability
 - In flight shut down rate (IFSD) ~ 2×10^{-6} hr
 - Mean time between overhauls 8,000~16,000 hrs



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Innovation vs. Novelty

- Innovation
 - “the alteration of what is established by the introduction of new elements or forms”*
- Novelty:
 - “An...amusing object...relying for its appeal on the newness of its design”*

(*Source: *OED*)

Impressive Novelties

Technical tour de forces



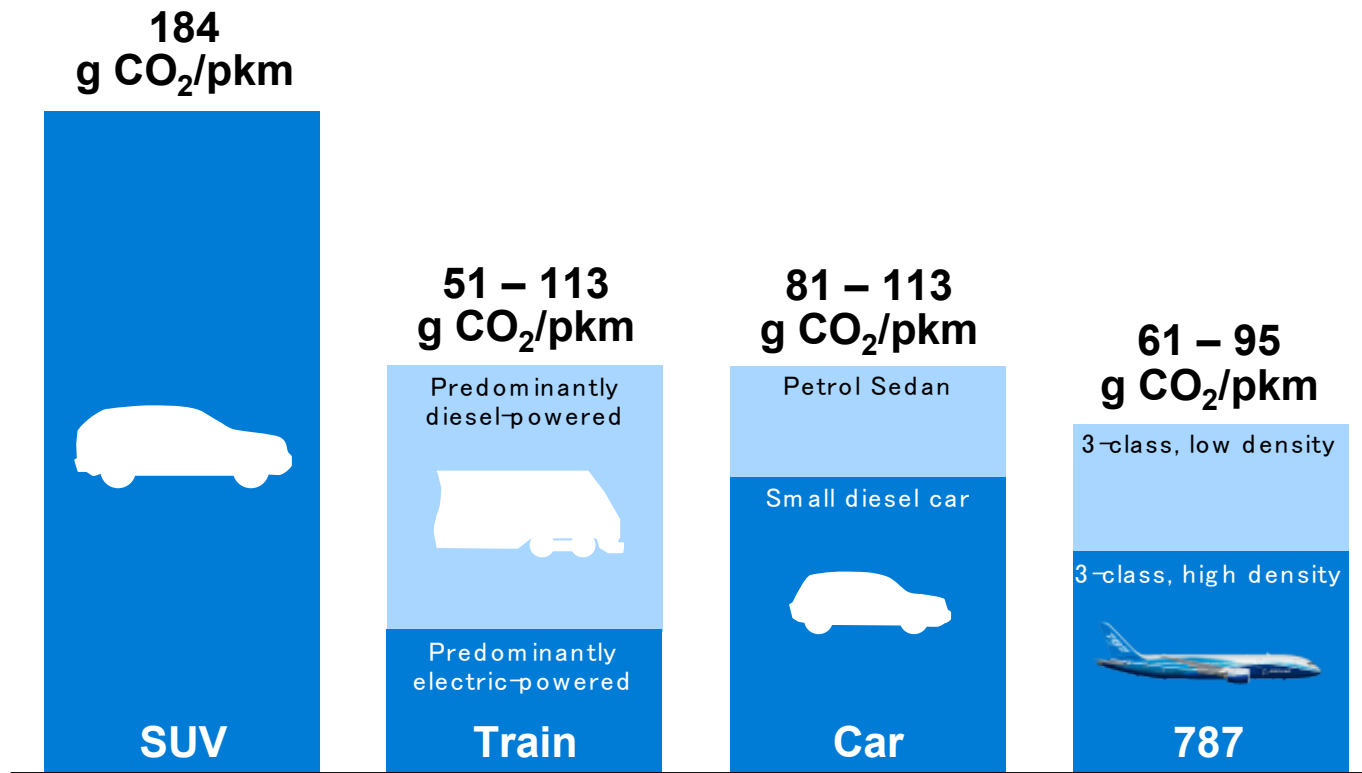
Human Power



Solar Power

Boutique aircraft can be fun & fascinating
but where's the (economic) beef?

Aircraft As Low Carbon Transportation

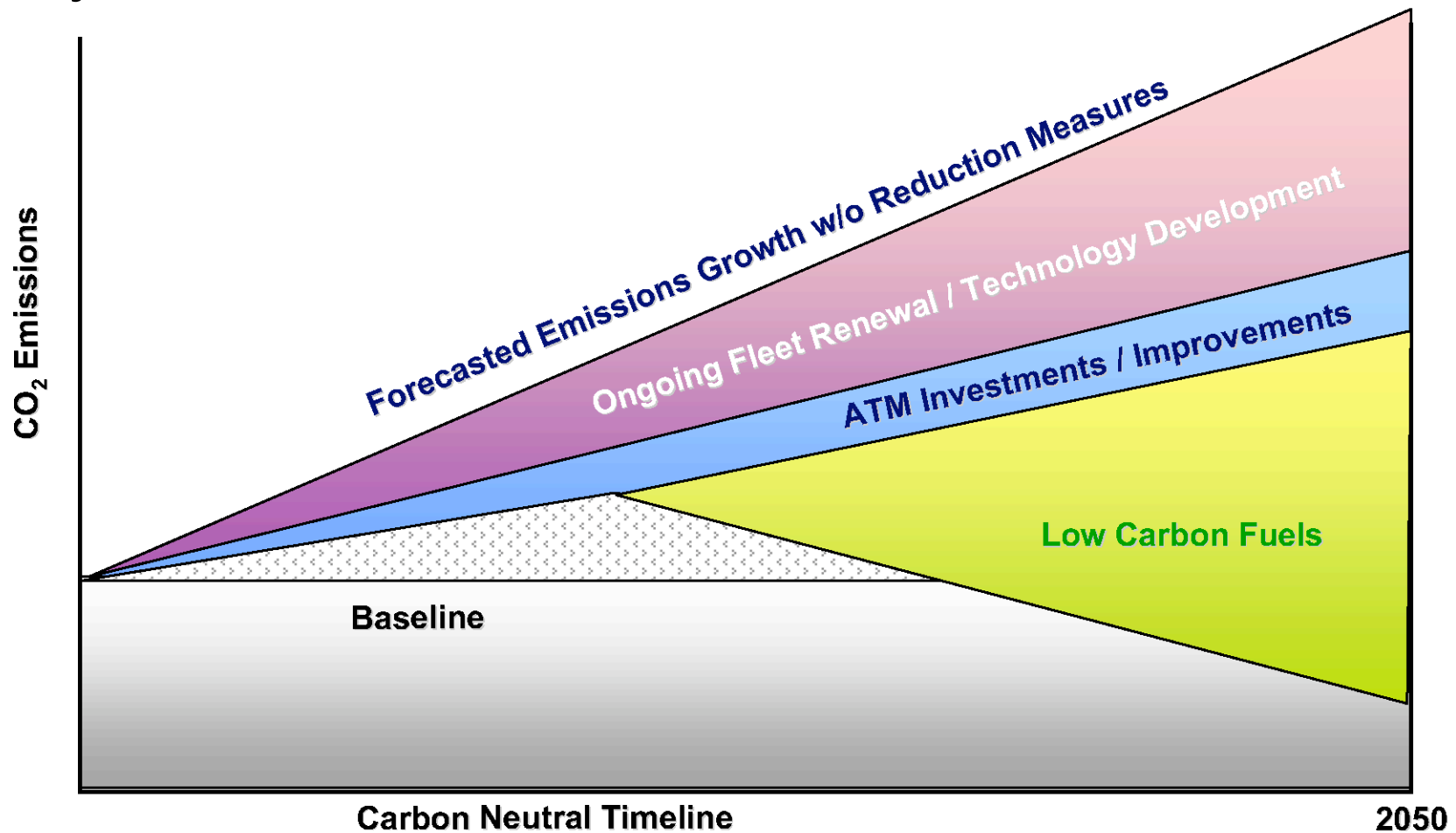


- Equivalent grams CO₂ / passenger kilometers, assuming average modal load factors (1.6 passengers for SUV and cars, 38.7% for diesel train, 47.6% for electric trains, 70% for low density 787 and 90% for high density 787).
- Electric trains are assumed to have typical CO₂/kWh electrical generation factors, reflecting a mix of fossil fuels, nuclear and hydroelectric sources.

Courtesy the Boeing Company

Carbon Neutral Growth – Carbon Free Flight?

Only Possible with a Fuel Based Solution



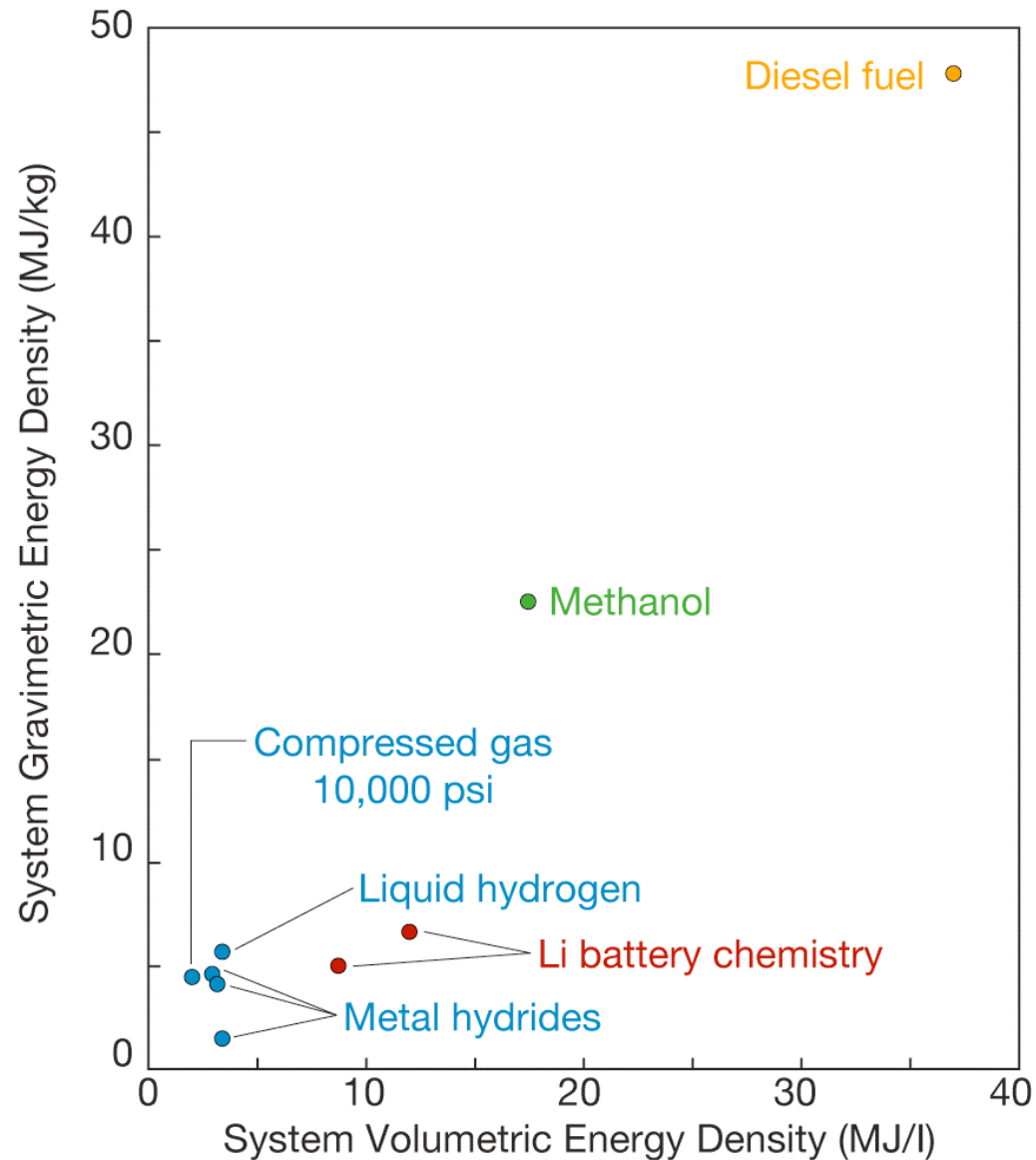
Courtesy the Boeing Company

Fuel Energy Per Unit Mass

	MJ / kg	\$ / MJ
Beef	4.0	2.0
Whole Milk	2.8	0.32
Honey	14	0.29
Sugar	15	0.07
Peanut Butter	27	0.15
Bacon	29	0.14
Vegetable Oil	36	0.06
Kerosene	42	0.010
Natural Gas	45	0.005
Hydrogen	117	0.05

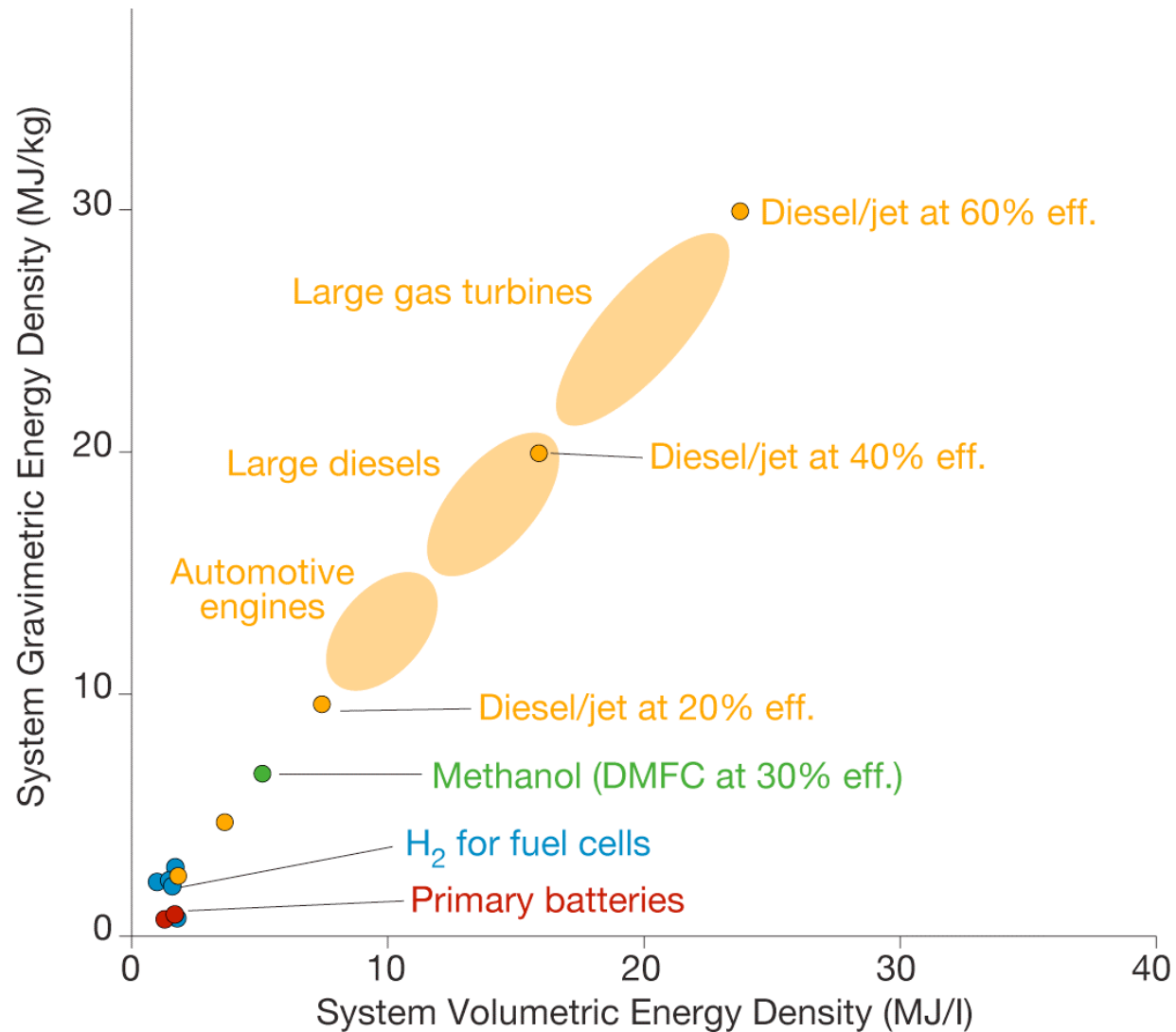
(from *The Simple Science of Flight*, by H. Tennekes)

Chemical Energy Sources For Flight



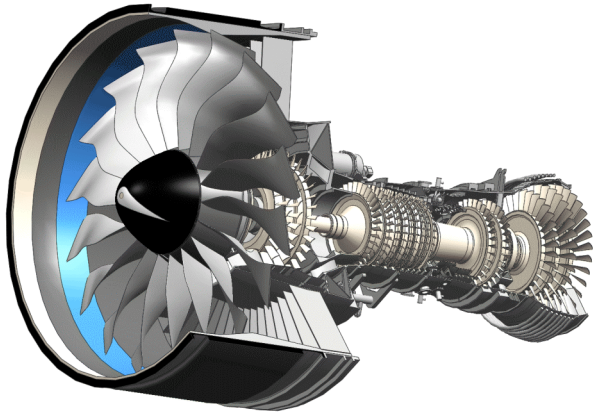
Practical Energy Density Of Fuels

– Fuel & Container Only –



Near Term Propulsion Options

Jets or Propellers?



Turbofan



Single Rotation
Propeller

- What's new?



Counter-Rotating
(CR) Propeller
AKA Open Rotor



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Same EIS Date, Same Speed, Same Fuel Burn Differentiated by Noise and Flight Speed



Open, Single Rotation

M=0.70~0.72

-5 dB to Stage 4



Open, Counter-Rotating

M=0.74~0.76

Stage 4



Ducted

M=0.80~0.85

-20 dB to Stage 4

- Same flight speed, same design date, on configuration optimized airplane

A \$1B Investment in Technology Innovation

25 Years to PurePower® Engines

40K Demo engine



11K Demo engine



30K Flight demos



Entry Into Service



1990

2000

2008

2013



Flight weight design



Gear Test Rigs



30K Ground demo



Entry Into Service

Thrust in thousands of pounds (K)



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Some Technology Challenges For NASA

Realistic but *hard*

- Eliminate aircraft noise as community concern
- Reduce aircraft climate change impact by 50-80%
- Reduce cost of access to space on a mission basis

The Innovator's Duty

Address Heilmeier's Questions

What is the problem or opportunity, why is it hard?

How is it solved/done today?

What is the new technical idea? Why can we succeed now?

What is the impact if successful? Quantified value?

How long will it take? ... Why?

What will it cost?

What Does The Future Hold?

“Aircraft flight is impossible.”

Lord Kelvin

“The [flying] machines will eventually be fast; they will be used in sport but they should not be thought of as commercial carriers.”

Octave Chanute, 1910

“By no possibility can carriage of freight or passengers through mid-air compete with their carriage on the earth’s surface.”

Hugh Dryden, 1908

“There has been a great deal said about a 3,000 mile rocket. In my opinion such a thing is impossible for many years. I think we can leave that out of our thinking.”

Vannevar Bush, 1945

“...the Gas Turbine can hardly be considered a feasible application to airplanes...”

Committee with Von Karman, Millikan, Kettering, 1941

(Reported by N. Augustine)



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